How to Use CGWAVE with SMS: An Example for Tedious Creek Small Craft Harbor

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) presents an example of how to use the numerical model CGWAVE within the Surface Water Modeling System (SMS) Version 8.0 environment. Updates of SMS are frequent and may result in different control options. This CHETN was completed as part of the Tedious Creek, MD, work unit of the Monitoring Completed Navigation Projects program.

BACKGROUND: The SMS is a comprehensive graphical user interface (GUI) for model conceptualization, mesh generation, statistical interpretation, and visual examination of surface-water model simulation results. The version described herein is SMS Version 8.1. It is the main model delivery system with pre- and post-processor capabilities for all the CHL numerical models including ADCIRC, TABS (RMA2, RMA4, SED2D), ADH, HiVEL, M2D, STWAVE, BOUSS2D, and CGWAVE. These integrated or interconnected models provide circulation and/or wave climate from a range of coastal processes including waves and currents, sediment transport and morphology change, channel infilling and inlet morphology, and dredged material fate. SMS provides the tools and macros for editing and display for mesh development, coordinate conversion, model connectivity, animations, and comparisons.

SMS is divided into modules. The modules discussed herein are: Scatter, Map, and Mesh. The Scatter module stores scattered data sets, such as bathymetric data, and interpolates them to model grids and meshes. The Map module is used to create and manipulate conceptual models. The user can create and define attributes for feature objects, such as points, arcs and polygons, which define the system being modeled. Images, such as scanned maps or photographs can be helpful in this process and also make the display easier to interpret. Drawing objects, such as text, lines, and arrows further improve the readability of the display. The Mesh module and other modules are used to create and manipulate numerical models. They allow (a) graphical interaction with mesh/grid editing, boundary conditions, model parameters, and materials, and (b) visualization of numerical model layout, and solution data. Each of the modules used to create and manipulate numerical models may have different coverages associations. For instance, the Mesh module has many coverages, one for each model supported.

CGWAVE CAPABILITIES: CGWAVE is a general purpose, state-of-the-art finite element wave prediction model based on the elliptic mild-slope wave equation that is applicable to harbors, open coasts, inlets, islands, and fixed and floating structures. It includes the effects of wave refraction, diffraction, and dissipation from bottom friction, wave breaking, nonlinear amplitude dispersion, and harbor entrance losses. Wave breaking can also be added during post-processing if not activated during model execution. Bottom friction is especially important for long waves. CGWAVE does not have any wind input or wave runup/overtopping of structures. Wave-current and wave-wave interaction processes are in development.
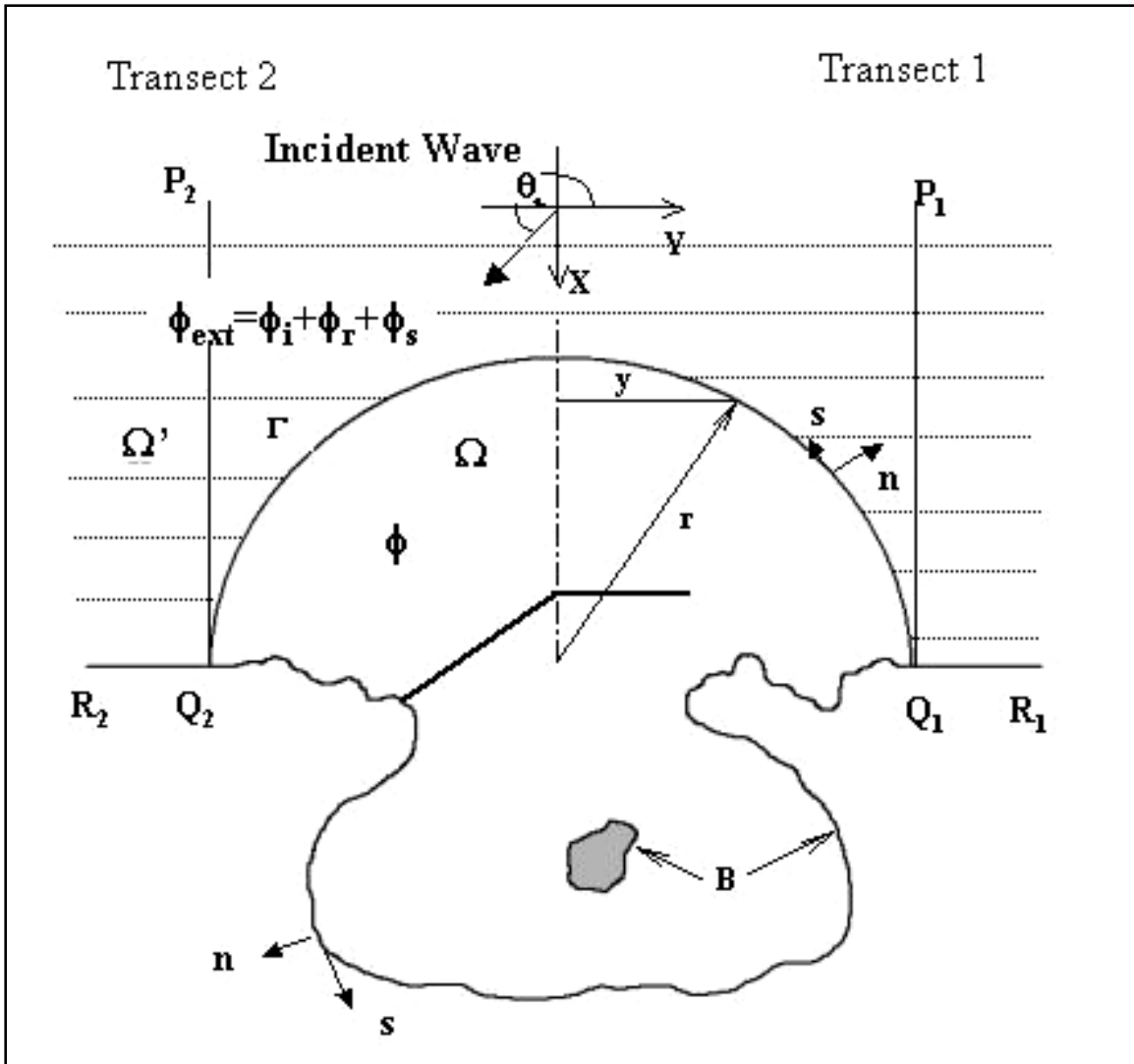
Figure 1.   Example of a CGWAVE model domain

CGWAVE accepts arbitrary domains (Figure 1) and structures using linear triangular finite elements. The large number of discretized equations is solved with iterative and direct solvers as a steady state problem. Convergence is guaranteed, but can be extremely slow on PC's with large model domains. The ERDC High Performance Computing Center's (HPC) supercomputers can be used to quickly solve large problems. Currently, the Silicon Graphics, Inc. (SGI) solver available on the SGI Origin 3000 supercomputer named "Ruby" provides reasonably fast run times with CGWAVE. The model output is then transferred back to the PC for post-processing.

Both regular and spectral waves can be input. Spectral or irregular waves can be simulated by combining regular wave cases. The wave direction is the direction the waves travel to and is measured positive in a counterclockwise direction from east (i.e., 0 deg). Short and long waves, including tsunamis, can be modeled.

Additional information on CGWAVE can be obtained from Demirbilek and Panchang (1998) and the Web site at *http:/chl.wes.army.mil/research/wave/wavesprg/numeric/wentrances/cgwave.htp*.

STWAVE vs. CGWAVE: What is the difference between these two numerical models? When do you use one instead of the other? Both are used for wave modeling, but the relative scales are different. Wave modeling can be grouped into three classes or relative scales: generation, transformation, and local scale. The generation scale deals with waves as they are formed or generated in deep water. The transformation scale describes wave transformation in deep to intermediate level water depths. The finite difference STWAVE model falls in this class of numerical models and includes the coastal processes of refraction, shoaling, wave-current interaction, wave growth, and depth-limited wave breaking. The local scale class is for nearshore or local modeling of intermediate to shallow water. The finite element CGWAVE model is in this category. Thus, the STWAVE can be used to transform deepwater waves to a depth coinciding with the offshore boundary of the CGWAVE model.

CGWAVE PROCEDURE: The procedure for running CGWAVE within SMS can be divided into four parts:

   a. Create a conceptual model

   b. Generate the finite element mesh

   c. Run the model

   d. Post-process the results

Each of these steps are discussed in the following paragraphs. Since SMS does not have an "undo" function, it is a good idea to save your work early and often.

CREATE A CONCEPTUAL MODEL: To create the conceptual model, which SMS uses to generate a mesh-based numeric model, you should (a) import and register a background image, (b) gather coastline and bathymetric data, (c) determine the coordinate system and datum reference for the project, and (d) conceptualize the study area with a CGWAVE coverage type.

Background Image. It is useful to have an aerial photograph or image of the project area to see if the conceptual model is correct. Image data is input in the Map module in tiff or jpg formats using the **File|Open** command. These images have to be registered or geo-referenced to state plane coordinates, meters. The three registration points shown in Figure 2 must be moved to known coordinate positions or a pre-existing GIS type "world file" must be read into SMS to geo-reference the image. In this example, the *.jpg file was opened first and then the .jgw world file was input using the **Import World File** button. If an SMS image file (.img) was previously saved, it can be opened in lieu of the world file referencing. The ASCII image file tc_overlay_metric.img opens the file Tedious_small.jpg and provides the proper registration information.

Coastline and Bathymetric Data. The CGWAVE model requires bathymetric and coastline data. Bathymetric data is input in the Scatter module in an "xyz" file format, using the **File|Open** command. The x and y coordinates should be in state plane and true north. All values of water depth should be in meters and positive downward. Bathymetry should include the model domain and a
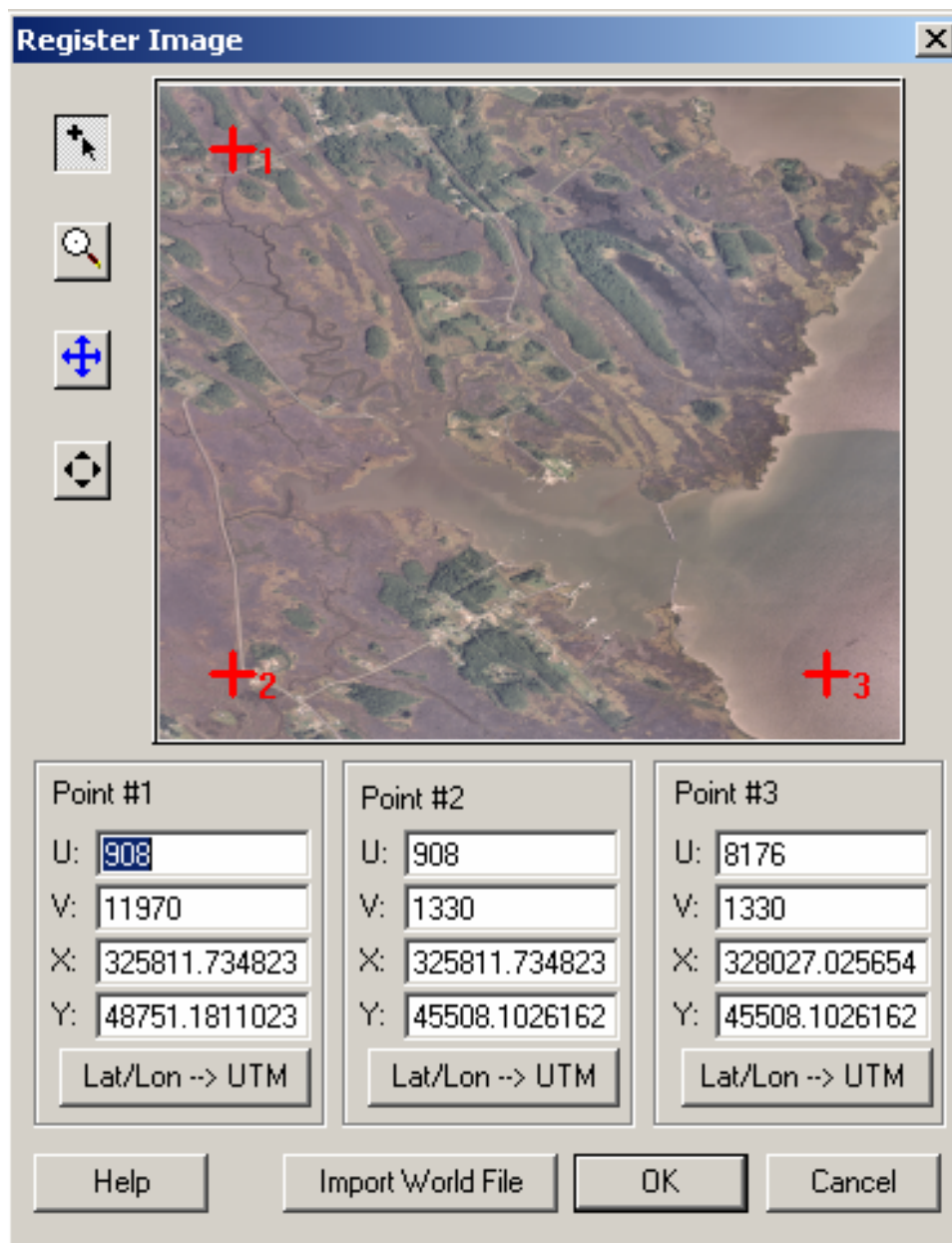
Figure 2.   Registering image of Tedious Creek, MD

sufficient distance offshore to cover the one-dimensional (1-D) transects (see following section). Sources of bathymetric data are previous studies, local surveys, and databases including GEODAS, the worldwide geophysics database. In this study, survey data from August 2001 were available in the file Tedious_Aug01_harbor_water_depth_meter.xyz for the inner harbor and Ted_cr_mllw_m.xyz for the offshore area. The bathymetric data are named elevation, by default.

Coastline data defines the "wet" edge of the model for the land-water interface. The data file Tedious_Aug01_landedge_survey_meter.xyz was obtained by walking the bank line with a hand-held global positioning system (GPS) and was used to define the land edge. It was also input in the

Scatter module. Figure 3 shows the bathymetry and coastline scatter sets overlaid on the background image.

Coordinate System and Datum Reference. All data must be geo-referenced to be useful. So the bathymetric and coastline data must also be converted to the same coordinate system to be properly merged. A copy of the "*CORPSCON*" conversion utility is contained within SMS. Since the earth is round, it is not possible to have exact x/y-coordinates based on latitude and longitude. Thus, the world is divided into smaller rectangular sections that permit more precise measurement in horizontal and vertical directions. The Web site at the University of Texas gives a good description of the different coordinate systems *http://www.ncgia.ucsb.edu/education/cirricula/giscc/units/ u013/u013.html*.

Figure 3.   Scatter data points representing bathymetric survey locations for Tedious Creek

Horizontal coordinate systems supported within SMS are: (a) geographic, (b) State Plane, (c) Universal Transverse Mercator (UTM), and (d) NAD 27/83/HPGN coordinates in meters, U.S. survey feet, or international feet. Geographic coordinate systems consist of latitude, longitude, and height measurements, with the prime meridian and the equator as reference planes to define latitude and longitude. The State Plane System was developed in the United States in the1930's to provide a national datum and was based on the North American Datum 1927 (NAD 27), with coordinates in feet. In 1983 the NAD 27 was superseded by the NAD 83 system with units in meters. Smaller states may have only one zone, where larger states may be divided into several zones. UTM coordinates are composed of UTM zone numbers designating 6-deg longitudinal strips and UTM zone characters designating 8-deg latitude zones. Vertical coordinate systems support NGVD 29 or NAVD 88 in meters, U.S. survey feet, or international feet. The mean low low water (mllw) datum is usually used. These conversions also make sure all data is aligned according to true north.

Figure 4 is an example of a single point conversion within SMS for the offshore directional NORTEK Aquadopp wave gauge used in the field measurements at Tedious Creek during April to July 2001. Water depth was 2.3 m (7.5 ft). The gauge was located at lat. 38.24482° and long. 76.03995°. Click on the **Edit|Single Point Conversions** command to open the conversion routine. Values can be input in decimal degrees or in degrees, minutes, and seconds. The input and output horizontal systems are geographic NAD 27 (US) and State Plane NAD 27 (US), respectively. The output State Plane Zone is Maryland – 1900. These can be determined using the *Help* menu and

Figure 4.   Single point coordinate conversion

locating the particular site on the maps. The vertical system coordinates are not used here, but still must be input correctly. The input and output vertical systems are local and NGVD 29 (US), respectively, with a value of 7.5 U.S. survey feet. Clicking the **Convert** button results in an x value of 327884.3540 m, y of 46117.0956 m, and z of 2.2860 m.

In summary for the Tedious Creek project, all coordinate systems were converted to meters. The horizontal coordinate system is the State Plane "NAD27 Maryland-1900," and the vertical datum reference is NGVD 29 (US).

Conceptualize Study Area. The conceptual model should define (a) the model domain, (b) feature arcs for the coastline boundary, open ocean boundary, and any additional structures, and (c) the 1-D transects. Before you begin to conceptualize the study area, create a CGWAVE coverage by selecting *Feature Objects|Coverages* in the Map module.

Model domain. The first step toward defining the numerical model domain is having a mindset of the study purpose and the computational capability (processor speed and memory) to solve the problem. The main items of interest should be within the inner one-third of the model domain. CGWAVE uses a size function, which takes into account the shortest expected wavelength of concern and the water depth, to define the required resolution for accurate computation. Although this will be discussed in detail later, it is a good idea to do a quick estimate of the anticipated number of elements.

Figure 5 shows the model domain for the Tedious Creek model. The west or back end of the model was truncated in water within the harbor instead of the actual shoreline to reduce the number of nodes and elements required. Because it is marshy and shallow in the upper reaches of the harbor, it was not necessary to model these areas to achieve accurate results in the study area.

Feature arcs. Create the coastline arc by selecting *Feature Objects|Create Coastline*. SMS will automatically examine the bathymetry contours to create a feature arc at a user specified elevation. Enter the minimum water depth to define the coastline or land-water interface. A value of 5 cm (i.e., 0.05 m) is usually selected as the coastline water depth to insure that all elements are wet. Adjustments can be made in the coastline data file to make sure there are no zeros in the definition. The coastline arc is shown in brown in Figure 5.

The ocean boundary is semicircular for a coast, but can be circular if the domain is an island. The radius of the semicircular arc of the ocean boundary is selected to include a distance up and downcoast and offshore to permit sufficient wave transformation. Choose the *Select Feature Vertex* tool and select two end point vertices for the ocean boundary intersection with the coastline arc. The points should be approximately equidistant from the center of the harbor. Be sure to hold the shift key down while selecting both vertices. The domain is defined in the **Feature Objects|Define Domain** command. Choose the semicircular option for a shoreline. If the arc is oriented landward instead of offshore, select the arc to reverse direction using the **Feature Objects|Reverse Arc Direction** command in the Map module. Since the arc direction is determined by which node of the arc is selected first, deleting the original arc and re-entering the two end points in reverse order can also reverse the ocean boundary. The semicircular open ocean arc is shown in blue in Figure 5.
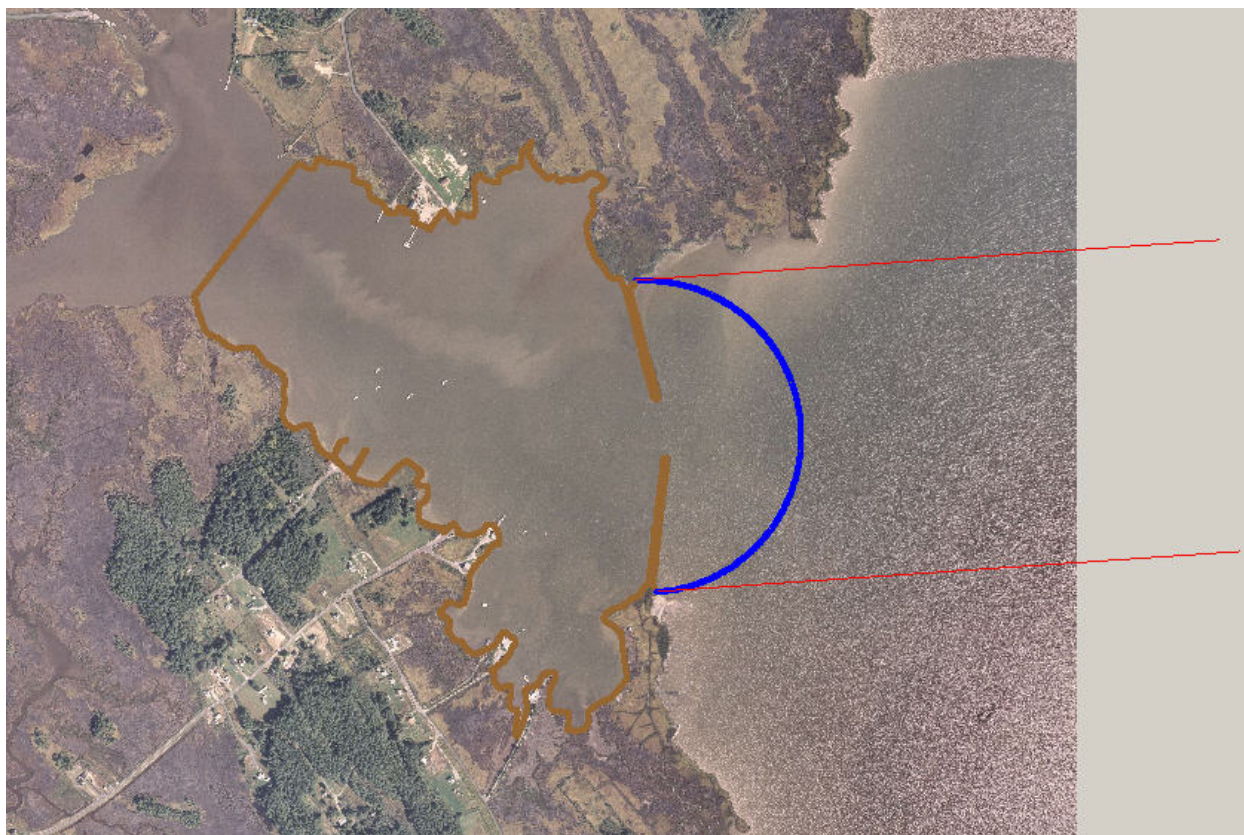
Figure 5.   CGWAVE model boundary for Tedious Creek, MD

You can further define the area being studied by creating additional feature arcs. This is done using the *Create Feature Arc* tool in the Map module. The Tedious Creek model has a feature arc at each major change in direction along the coastline boundary. In the vicinity of the public piers, there are many arcs to properly define the piers. The coastline arc near the piers was broken into several unique arcs and vertices were moved to follow the exact layout of the piers (see section on "Reflection Coefficients").

1-D transects. The 1-D lines are used to transform offshore wave data to the ocean boundary of the model to increase the reliability of the model's predictions in projects where exterior bathymetric effects might play an important role. In cases where 1-D transformation is used, it will no longer be necessary to use other spectral wave models to transform waves from deep water. The CGWAVE model uses a 1-D mild slope wave equation to solve for the wave transformation from an offshore point with known wave climate to the CGWAVE semicircular ocean boundary. The assumption is that the bathymetry only changes in the offshore direction seaward of the ocean boundary; thus, simplifying the calculations.

A 1-D transect extends offshore from each side of the model domain (Figure 1 and Figure 5) with origin at the intersection of the semicircular boundary and the coastline boundary. Since the ocean boundary is curved, the values of wave transformation are input from the transect which is closest to the point along the semicircular boundary. Near the center, the values are averaged between the two transects. Each transect includes bottom friction and reflection, if these processes are activated. It is

important to activate these processes unless the water depth becomes deep close to shore (i.e., in essence deepwater waves at the semicircular boundary) or the depth is relatively constant all along the ocean boundary.

GENERATE FINITE ELEMENT MESH: To generate a good mesh for CGWAVE, you should (a) define the mesh resolution, (b) build polygons, (c) assign reflection coefficients, (d) create mesh, (e) check mesh quality, and (f) assign CGWAVE model parameters.

Define Mesh Resolution. The mesh in the CGWAVE model is wavelength-dependent. Since wavelength is a function of the water depth and wave period, it is important to define the design or smallest wave periods of interest to the project. A minimum of 6 to 10 elements in the finite element mesh per wavelength is required to properly define the domain. Fifteen elements per wavelength is ideal. For relatively shallow projects like Tedious Creek, this is critical as the mesh may require a large number of elements, severely taxing the model's capabilities. Ten or more elements per wavelength give the best resolution of the wavelengths.

Size function. The size function is calculated in the Scatter module. This is a two-step process: create the wavelength function and scale wavelength to create the size function. The first step (Figure 6) is to define and create the wavelength by specifying the design wave period in the **Data|Create Data Set** command of the Scatter module. Turn off all options except for the *Transitional Wavelength and Celerity* and enter a value of 6 sec for the design wave period. This is the smallest wave period with significant energy and frequency of occurrence for the project site. Make sure that the water depth data set (i.e., elevation) containing the bathymetry data is active. Two new data sets, *Transition Wavelength* and *Transition Celerity*, are created. The data set name can be left with the default *Transition* or other more descriptive name. The *Transition Celerity* data set is not needed and can be deleted in the *Data Browser* if desired.

The next step (Figure 7) is to create a size function data set based on the *Transition Wavelength* in the **Data Calculator** command. Select the *Transition Wavelength*, the divide symbol and enter the value of 10 in the formula box. Define the new computed data set as something like **Size10_T6** in the *Result* box to document and click on the **Compute** command. This new data set will be used in calculating the finite element mesh resolution so that the element edges have a length of the order of this maximum size. The mesh will be denser where the size values are smaller.

Build Polygons. The second step in the generating finite element mesh is to build the polygons. Switch to the Map module and select the **Feature Objects|Build Polygons** command to construct polygons from the feature arcs. The **File|Get Info** command or the *Get Module Info* button on the toolbar will bring up a dialog that will tell you how many polygons were created. In this example, there should be three polygons: one for the ocean and two for the detached breakwaters.

Once you have created polygons, you can use the *Select Feature Polygons* tool to select individual polygons. Activate the *Select Feature Polygons* tool, and double click a polygon to bring up the *Polygon Attributes* dialog. This dialog allows you to set various options, which SMS will use to create the finite element mesh. If *Mesh Type* or *Bathymetry Type* is set to an option that is dependant on a scatter set, a **Scatter Options** button will appear below the combo box, allowing the user to select further options.

Figure 6.   Creating a wavelength function for a wave period of 6 sec

Ocean polygon. For the ocean polygon (Figure 8), set the *Mesh Type* to **Scalar Paving Density**. This tells SMS to generate a mesh with a density interpolated from a size scatter set. Click the **Scatter Options** button to open the *Interpolate* window. Select **Size10_T6** for the *Scatter Set to Interpolate From*, **Linear** for the *Interpolation Option*, and **Single Value** with a value of 0.0 for the *Extrapolation* box.

For the *Bathymetry Type,* input **Scatter Set** to indicate that the mesh elevations will be interpolated from scatter set data. Once again, a **Scatter Options** button will appear and selecting this button brings up a similar *Interpolation* dialog. The same input as before should be entered except that the elevation data set should be input for the *Scatter Set to Interpolate From.*

Finally, the *Polygon Type/Material* is input as **Ocean**.

Breakwater polygons. The other two polygons represent the detached breakwater polygons. The attributes for these polygons will have a *Mesh Type* of **None** and the *Polygon Type/Material* as **Land**.
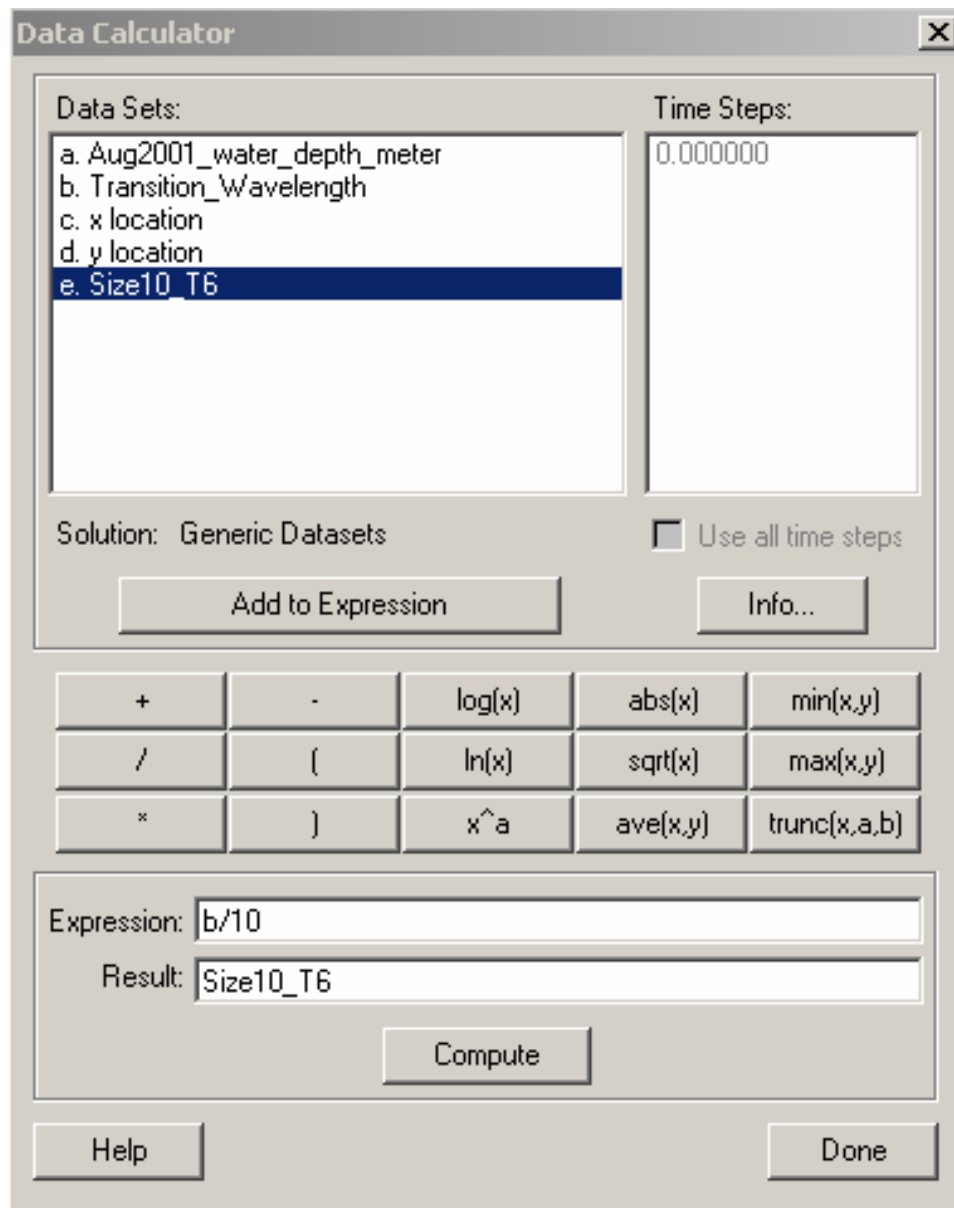
Figure 7. Create size function using data calculator

Reflection Coefficients. The third step is to assign the reflection coefficients. Values range from 0.0 for no reflection (i.e., complete transmission) to 1.0 for complete reflection. Typical reflection coefficients for marshy shorelines and rubble-mound breakwaters are 0.1 and 0.5, respectively. The public piers at Tedious Creek were constructed using vertical sheet-pile walls that did not extend to the bottom. The appropriate reflection coefficient of 0.9 was assigned for them. In the Map module, activate the *Select Feature Arc Tool* and double click on each arc to set the appropriate reflection coefficient. This process is illustrated in Figure 9. Thompson et al. (1996) provides a good reference for typical reflection coefficients for short waves.
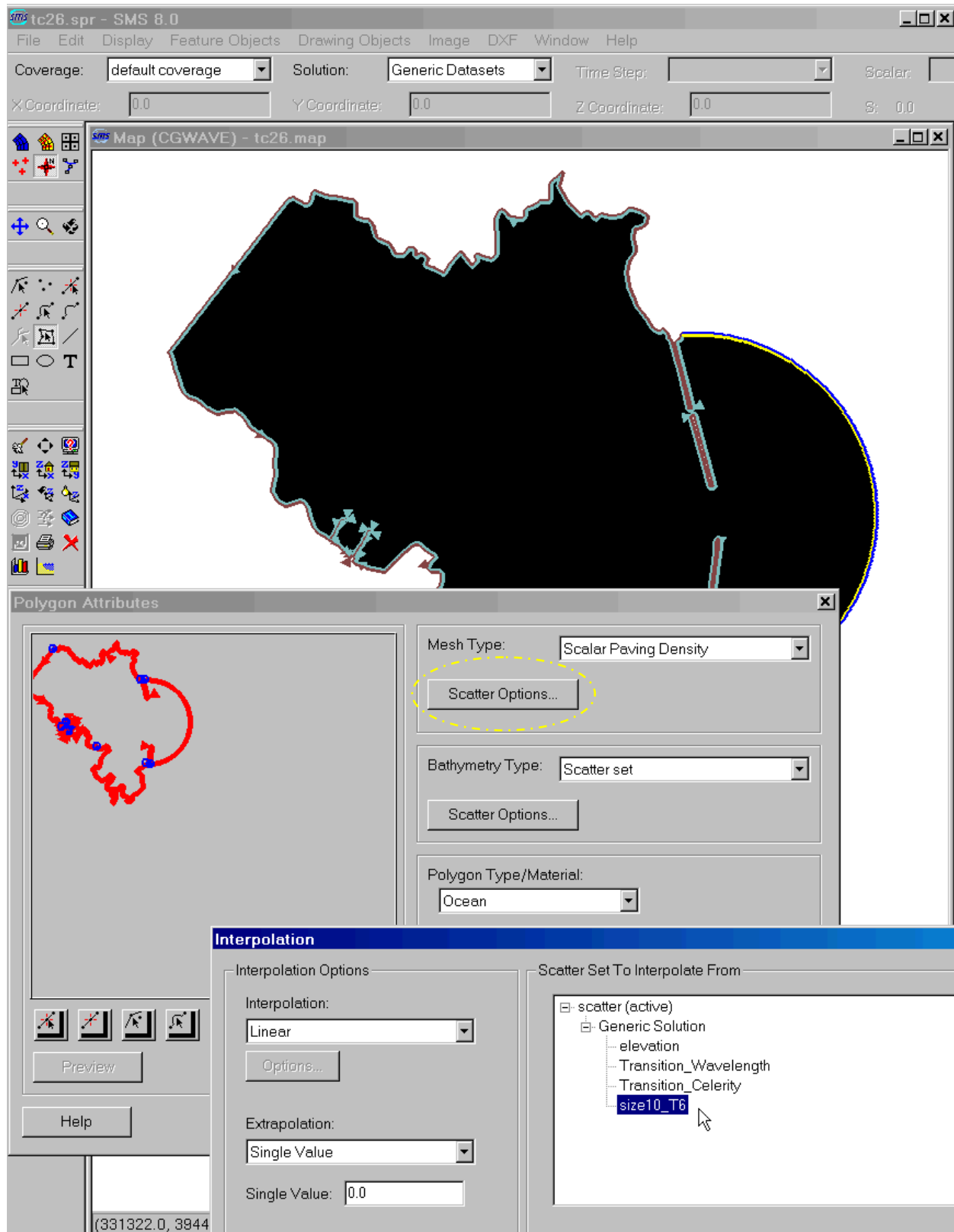
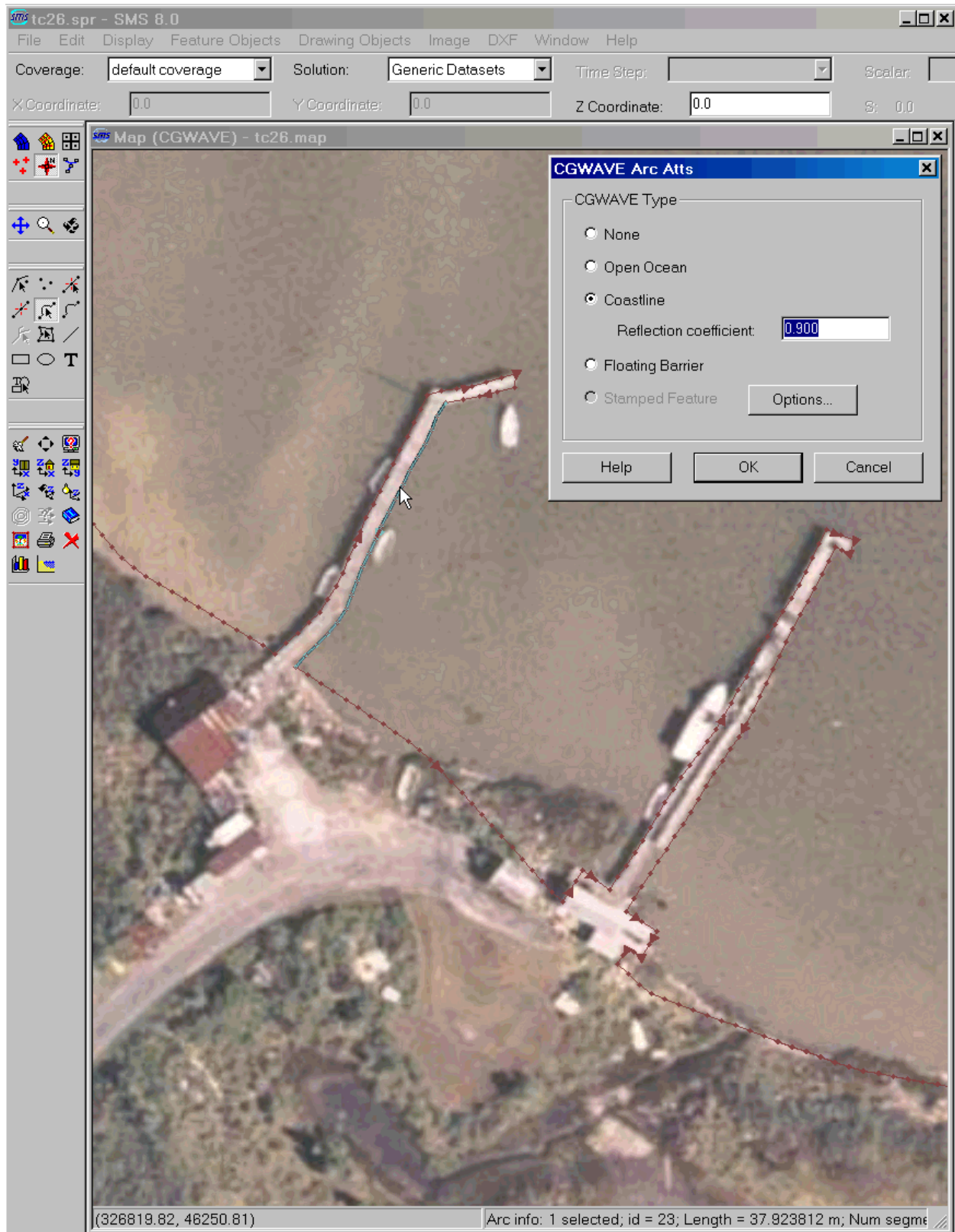Figure 8.   Defining attributes for polygon representing ocean material type

Figure 9.   Assigning unique reflection coefficients to public piers

Create Mesh. This is potentially a long process, depending on the size function and the extent of your domain. It is a good idea to save your work first using the **File|Save** command. Then, select the **Feature Objects|Map to 2D Mesh** command to begin the mesh generation.

Figure 10a and 10b illustrate the section of the created Tedious Creek CGWAVE mesh in the vicinity of the public piers and north breakwater. It illustrates the finite element mesh based on the T = 6 sec wave period and a size function defined by one tenth of the wavelength. The mesh contains a total of 339,042 elements and 171,265 nodes.

The primary purpose of this Tedious Creek study was to compare existing and authorized breakwater configurations. Figure 11 shows the two breakwater lengths relative to the channel outlines (red outlines). To accomplish this, a different mesh, using the same size function definitions, with the revised arcs representing the altered breakwater alignments, was created.

Check Mesh Quality. Element and mesh quality can be checked using the **CGWAVE | Model Check** command in the *Mesh* module. A mesh should have certain properties to insure that it runs efficiently during execution and does not cause instabilities in the solution. It should have good (a) elemental properties, (b) smooth bathymetric contours, (c) gradual area change, and (d) mild longitudinal depth changes. The elemental properties include aspect ratio, shape, and angle. An ideal element has an aspect ratio with sides that are the same length, no thin triangles, and interior angles greater than 10 deg. Adjacent elements should not have area or depth changes greater than 20 percent and should follow depth contours. If the *Model Check* does not return any serious errors, proceed to assign CGWAVE model parameters.

Assign Model Parameters. Defining the CGWAVE model parameters is a two-step process: (a) renumber nodestrings, and (b) input model control parameters.

Renumber nodestrings. Nodestrings are subsets of sequential nodes that allow specific parameter assignments and operations. SMS automatically creates nodestrings from the feature arcs when it generates the mesh. The nodestrings should retain the properties, such as reflection coefficients, that were already assigned to the feature arcs so all you need to do is renumber them. Renumbering gives new numbers to all the nodes in an orderly fashion to improve numerical bookkeeping. It only has to be done once after all mesh editing is finished. Typically, the best renumbering location is the ocean boundary nodestring. The mesh is renumbered by selecting the **Nodestrings | Renumber** command from the *Elements* menu after having selected a nodestring. The nodestring is used as a seed to start the renumbering process. The bandwidth option is the default.

Input model control parameters. Input the model control parameters by selecting the **CGWAVE | Model Control** command in the *Mesh* module. These include sections on (a) incident wave conditions, (b) nonlinear wave options, (c) open boundary, (d) 1-D wave transformation inputs, and (e) numerical solver. Incident wave conditions are input along the open ocean boundary and include wave period, direction, and amplitude. The amplitude is one half the wave height, and should not be confused with the wave height. Nonlinear wave options include bottom friction, wave breaking, and nonlinear dispersion. When first debugging a model, it is best to do the simple cases first. Then, a sensitivity analysis can be performed with these wave options to determine which should be exercised. Open boundary conditions should match those selected when generating the domain in the *Map* module. These are semicircular in the Tedious Creek example.
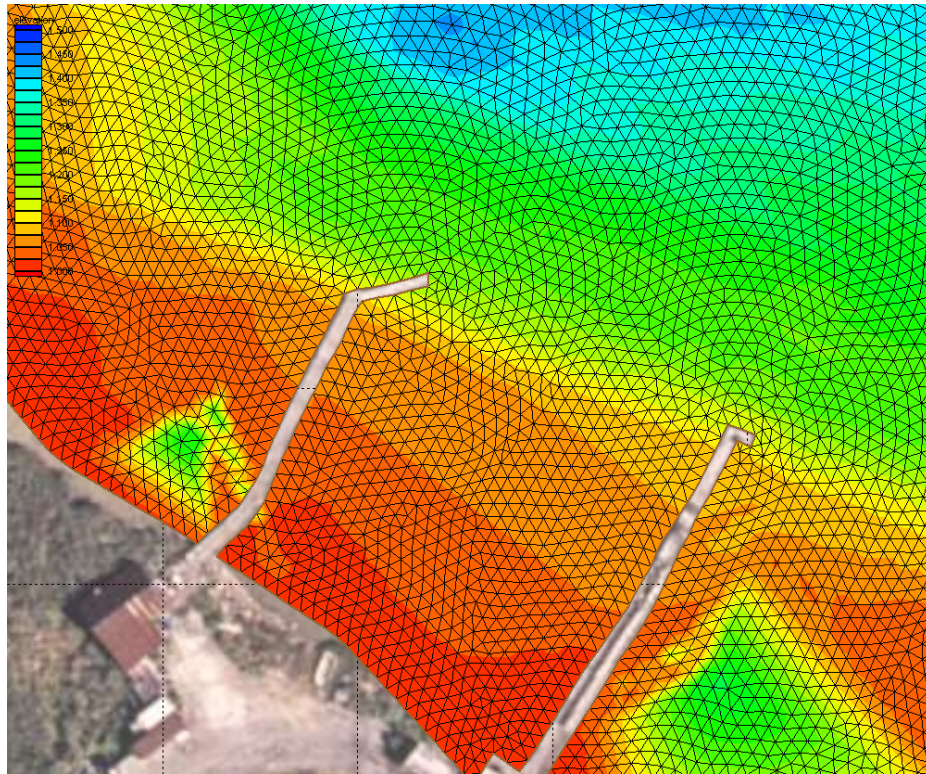
a. CGWAVE mesh and bathymetry in vicinity of public piers
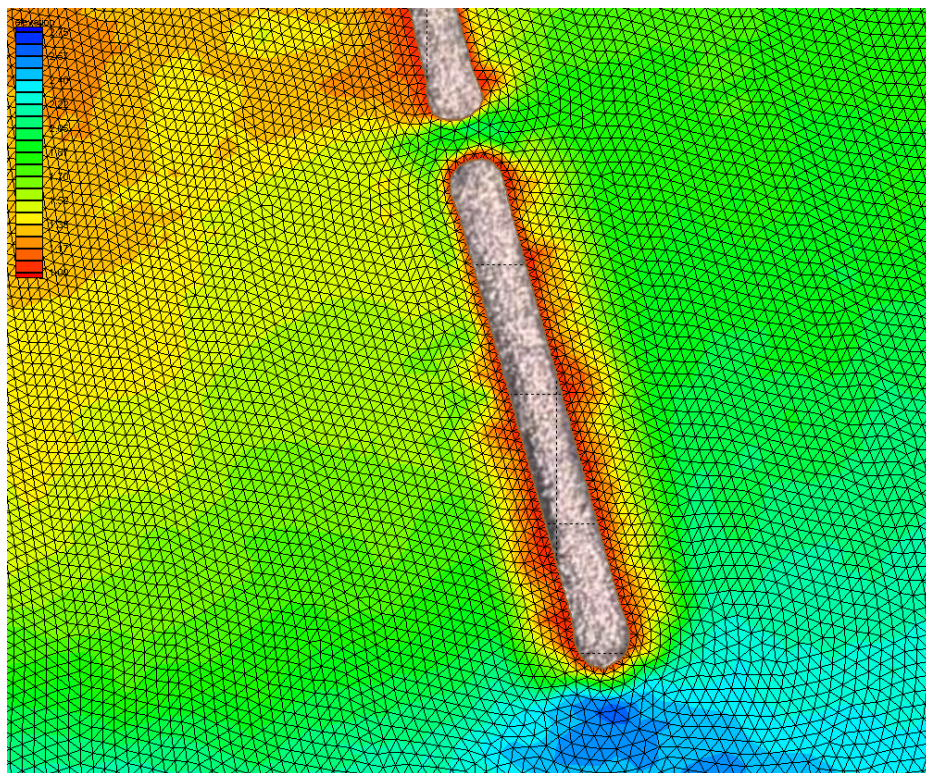
b. Bathymetry and mesh in vicinity of north breakwater for existing configuration

Figure 10. CGWAVE mesh and bathymetry details in vicinity of public piers
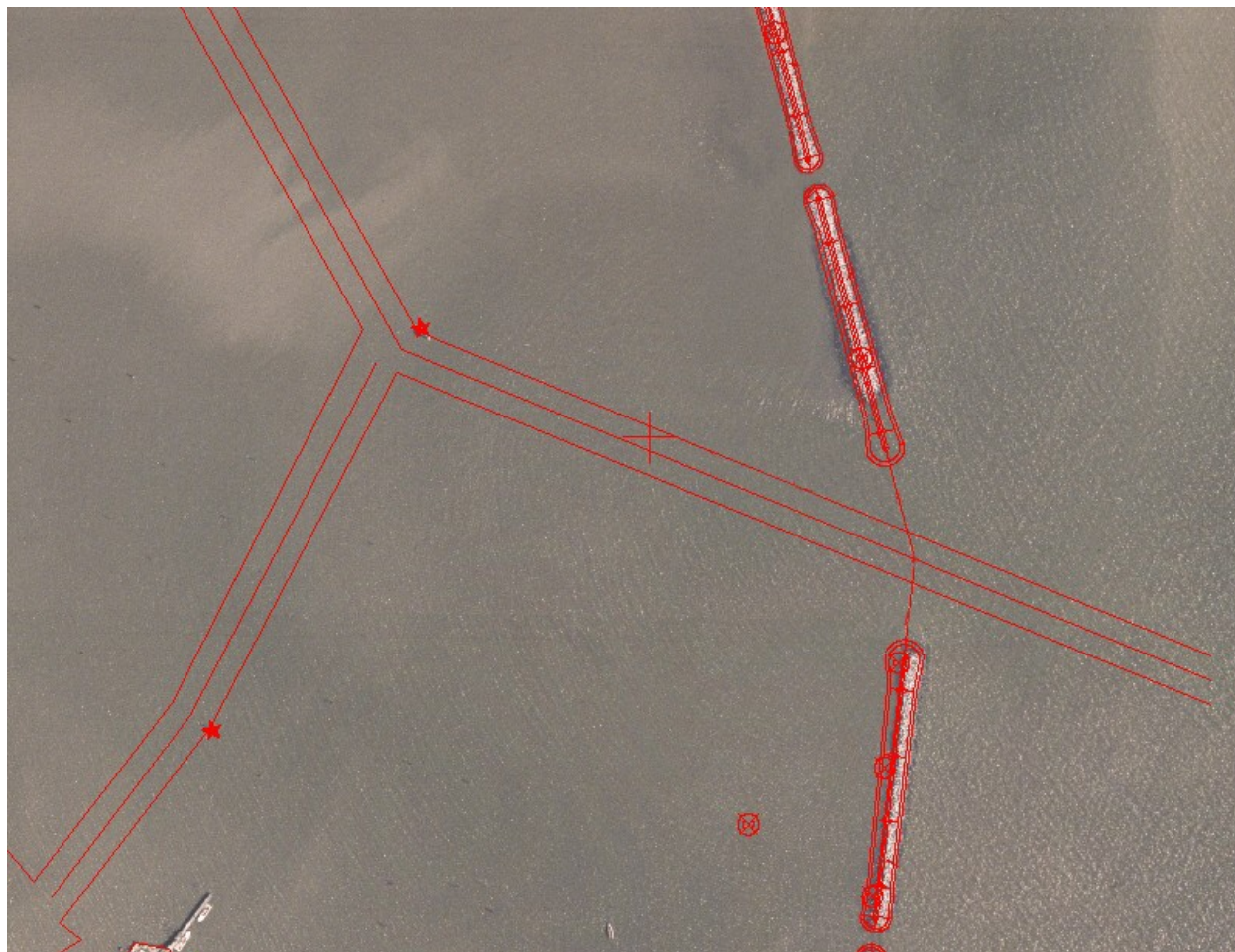and breakwater

Figure 11. Schematic of existing breakwater configuration (121.9-m (400-ft) gap) versus red outline of authorized breakwater alignment (91.4-m (300-ft) gap) with respect to channel outline

In the 1-D section, the user can specify either the number of nodes or the spacing in the 1-D lines. The spacing should be of the order of the smallest element, typically closest to the coastline, on the semicircle. A rule of thumb is that it is 1.25 times the offshore boundary radius divided by 100. The length of 1-D lines should extend sufficiently offshore, and may extend to the limits of the existing scatter set or further extended to pick up waves from buoys located beyond the scatter set. After selecting appropriate accuracy, the user selects either the "#1-d nodes" or the "1-d spacing" in the Compute section to calculate and save the 1-D lines (assuming the "Save 1-d file" under "Open Boundary" has been selected).

Finally, the numerical solver should be selected for the machine performing the calculations. If the model is small enough for the PC, then the "0 (or 1) Standard (PC)" solver(s) is selected. Otherwise, the "2 SGI Parallel" solver for the HPC Ruby SGI processor should be selected. There are different solvers for different HPC supercomputers, however.

RUN MODEL: Before running the model, save your file and make an additional backup copy with a different name in case the file becomes corrupted. Select **File | Save As** to save the file as a project file with suffix *.spr*. All geometry, input, and mesh information is contained in this file.

ERDC MSRC Resources. CGWAVE can be run from within SMS, but may be "painfully" slow depending on the size of your mesh. To run on your PC, select **CGWAVE | Run CGWAVE**. To run on the HPC Ruby SGI processor, you must have (a) Kerberos software (latest Version 20030506b for Windows) to insure secure communications between your PC and Ruby, (b) a SecurID card for obtaining a "ticket" to use the MSRC resources, (c) telnet software such as PuTTYtel (telnet) and (d) file transfer (i.e., FTP) capability, such as windows-based Filezilla. The latest version of the Kerberos software and telnet/ftp software can be downloaded from the MSRC Web site at *http://kirby.hpcmp.hpc.mil*. The *Documentation* tab on the left side of the screen is useful for details on the procedure. The ERDC MSRC Customer Assistance Hotline at 601-634-4400, option 1 is particularly helpful. Your CGWAVE files can then be copied to the Ruby (ASCII mode), executed, and then copied back to your PC for post-processing within SMS.

HPC Ruby Access. The first step is to gain permission to use the MSRC resources. All examples in this technical note assume the UNIX 6.5 shell. For the UNIX environment, it is advisable to have filenames without imbedded blanks. The University of Texas maintains a Web site with a good introduction to UNIX that is accessible at *www.utexas.edu/cc/unix/index.html*.

Initially, Kerberos and Filezilla software are used to copy two SMS output files from your PC to Ruby. These ASCII files are the CGWAVE run control input file (i.e., *.cgi) and the 1D (*.cg1) file. The asterisk is a placeholder for the project prefix selected for the study. After successful transfer of these files, a PuTTy telnet session to Ruby is required to issue UNIX based commands. The two input file names need to be renamed. The first file *.cgi must be renamed to be *.dat and the *.cg1 file must be renamed to *.1d. This is accomplished with the copy UNIX command that follows the format, "cp oldfile newfile".

CGWAVE Execution. There are four steps for executing CGWAVE within Ruby including (a) edit input file *.dat, (b) convert input to binary, (c) run CGWAVE, and (d) convert output to ASCII.

Edit the "*.dat" file, to reflect changes in incident wave period, amplitude, and wave direction in the title (for documentation) and the corresponding input field near the beginning of the file. Use the line editor "ed" or the full screen editor "vi" within the UNIX environment. A quick reference guide for the vi editor is *http://cac.uvi.edu/miscfaq/vi-cheat.html#toc*.

The second step is to convert the input ASCII run control file from SMS to binary format. The utility program dat2unf performs this conversion and creates three files *.par, *.geo, and *.grd corresponding to the input parameter, geometry, and grid files, respectively.

The third step is run CGWAVE using the executable file "pcgw_sgi_ser". This is the serial version for the SGI processor Ruby (i.e., same as option 2 under *CGWAVE | Model Control* described earlier). This is the main program that does the CGWAVE calculations. CGWAVE runs usually required less than 5 min to complete up to eight iterations. Thus, the serial version was adequate for the size of this model. Larger models would benefit from HPC's parallelized codes and solvers.

The fourth step is to convert the binary output file *0001.res generated from the third step to ASCII using the utility program res2out_sgi. The output file *.out from this program can then be transferred in ASCII mode to your PC via Filezilla FTP. It is a good idea to copy this output file to your home

directory on the Ruby with a descriptive name and suffix ".cgo" before transferring to your PC. SMS recognizes this file extension better than the *.out suffix. The *.che file is a documentation file recorded during each CGWAVE run (i.e., the pcgw command) to show the resolution obtained after each iteration. It should also be saved and transferred to your PC for future reference.

The final step after each run is to purge the miscellaneous files in the Work directory before executing an additional run. The user can create a short cut command in the alias file. For Tedious Creek, a short cut command "rmtcall" was created to remove these files so that they could be reused. The **up arrow** command works for cycling through all commands executed during a telnet session on Ruby. This is helpful if multiple runs are planned, so that the commands do not have to be typed in again. After all runs, type **Exit** and carriage return twice to exit Ruby.

POST-PROCESS RESULTS: CGWAVE calculates scalar and vector output information. Scalar data include wave height, phase, sea surface, dynamic wave pressures at three depths, and wave surface data. Vector data include particle velocity at three depths, wave direction, and wave velocity. Usually, the wave height and phase are the primary scalar quantities, and wave direction the primary vector quantity of interest.

Results from the CGWAVE runs can be post-processed in SMS. The first step is to FTP the ASCII result files to your PC using the Filezilla software. The next step is to import the *.cgo data files in the **Data Browser | Import** command of SMS.

Visualization methods in SMS include contour plots, vector plots, animations, and plots of observation data. The display options tool can be used to quickly access contour and vector display options.

Contours. To view contours of scalar data within SMS, select the *2D Mesh* tab in the *Display Options* dialog and turn on the *Contours* toggle. The *Contour Options* tab controls how the contours will be displayed. Contours can be linear, filled, or combined. The range and either the number or size of intervals can be specified. When you exit the dialog, the display will update with contours corresponding to the active scalar data set.

Vectors. To view a vector plot within SMS, turn on the *Vectors* toggle on the *2D Mesh* tab of the *Contour Options* dialog. The *Vectors* tab allows you to specify head size, arrow length, colors, and placement of vectors. The vectors will be displayed according to the active vector data set.

Animations. Animations can be created within SMS from the time-steps that are imported for each solution. A series of wave height contours or wave direction vector plots are formed to create the animation with the number of frames determined by the user. To create an animation, select the *Film Loop…*item from the *Data* menu in the Mesh module. An animation wizard will guide you through the process of creating a film loop. The film loop will be saved as an .avi file that can be viewed from within SMS or used with other software such as Microsoft PowerPoint.

Observation Plots. An observation coverage can be created to look at a cross section of wave heights along a user-defined transect. Data can be plotted within SMS and saved for further post-processing with other software (i.e., Axum, Excel, etc.).

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REFERENCES

Demirbilek, Z. and Panchang, V. (1998). "CGWAVE: A coastal surface water wave model of the mild slope equation," Technical Report CHL-98-26.

Thompson, E. F., Chen, H. S., and Hadley, L. L. (1996). "Validation of numerical model for wind waves and swell in harbors," *Journal of Waterway, Port, Coastal, and Ocean Engineering* 122(5), 245-257.

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